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Shape-factor effect on melting in an elliptic capsule

Sergei A. Fomin [a,*], Alexander V. Wilchinsky [b,1]

[a] *Fracture Research Institute, School of Engineering, Tohoku University, Sendai 980-8579, Japan*

[b] *Institute of Mathematics and Mechanics, Kazan State University, Kazan 420008, Russia*

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Abstract

An approximate mathematical model of contact melting of an unfixed material in an elliptical capsule is developed. The main characteristic scales and non-dimensional parameters which describe the principal features of the melting process are found. Choosing a special heat flux distribution on the wall of the capsule allows us to derive a closed-form evolution equation for the motion of the solid accounting for the energy convection in the liquid, expressed through the non-linearity of the temperature distribution across the molten layer. It is shown that the melting rate of the solid depends on the shape of the capsule. Generally, elliptical capsules show higher rate of melting than circular ones. Elongated capsules provide more effective melting than oblate ones, even though they have the same aspect ratios and vertical cross-sectional areas. This phenomenon is caused by the fact, that the pressure necessary to support the solid is larger for the elongated capsules than that for oblate ones, which leads to thinning of the molten layer along with the increase of the heat flux across it. The time required for complete melting can be achieved by the right choice of the shape of the capsule, which is specified by the value of the aspect ratio. The found influence of the capsule shape on the melting rate can be used for design and optimization of practical latent-heat–thermal-energy systems.

1. Introduction

Analysis of close-contact melting of a solid in a cavity is motivated by application in latent heat-of-fusion thermal-storage systems. Contact melting in a circular horizontal cylinder has been studied numerically by Saitoh and Hirose [1], analytically and experimentally by Bareiss and Beer [2]. Contact melting in a spherical capsule was investigated numerically by Moore and Bayazitoglu [3] and later, applying the technique proposed in [2], Bahrami and Wang [4], Roy and Sengupta [5] as well as Fomin and Saitoh [6] reported analytical solutions. The general scheme for the scale analysis of the contact melting problem was proposed by Bejan [7]. Although the aforementioned investigations highlight the main characteristics of contact melting inside a capsule, the effect of the shape factor of its cross-section was analysed only for elliptic cylinders [8]. Moreover, a simple linear distribution for the temperature has been assumed, which is acceptable only for very small Stefan numbers. In 1998, Saitoh [9] pointed out that the shape of the capsule is an important factor which should be taken into consideration for optimal design and construction of the latent-heat–thermal-storage systems.

In the present paper the approximate approach developed by Bareiss and Beer [2] is applied with the higher order of accuracy with regard to the temperature distribution for the mathematical modelling of contact melting in a horizontal elliptical cylinder and ellipsoidal capsule. It will be shown, that finding the temperature distribution to the second-order with regard to the Stefan number subject to the temperature distribution on the wall of the capsule, being constant in space, is tantamount to imposing the heat flux on the wall directly proportional to the heat flux at the melting interface. The influence of the shape of the capsule on the melting

* Corresponding author. Tel./fax: +81-22-217-7519.

1 Present address: Department of Space and Climate Physics, University College London, London, UK.

E-mail address: formin@rift.mech.tohoku.ac.jp (S.A. Fomin).

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